InterPlanetary Network Directorate
Deep Space Mission Systems

MODULATION TECHNIQUES for BANDWIDTH EFFICIENCY

Presented by:

WARREN L. MARTIN

DENNIS LEE

TSUN-YEE YAN

27 MARCH 2003

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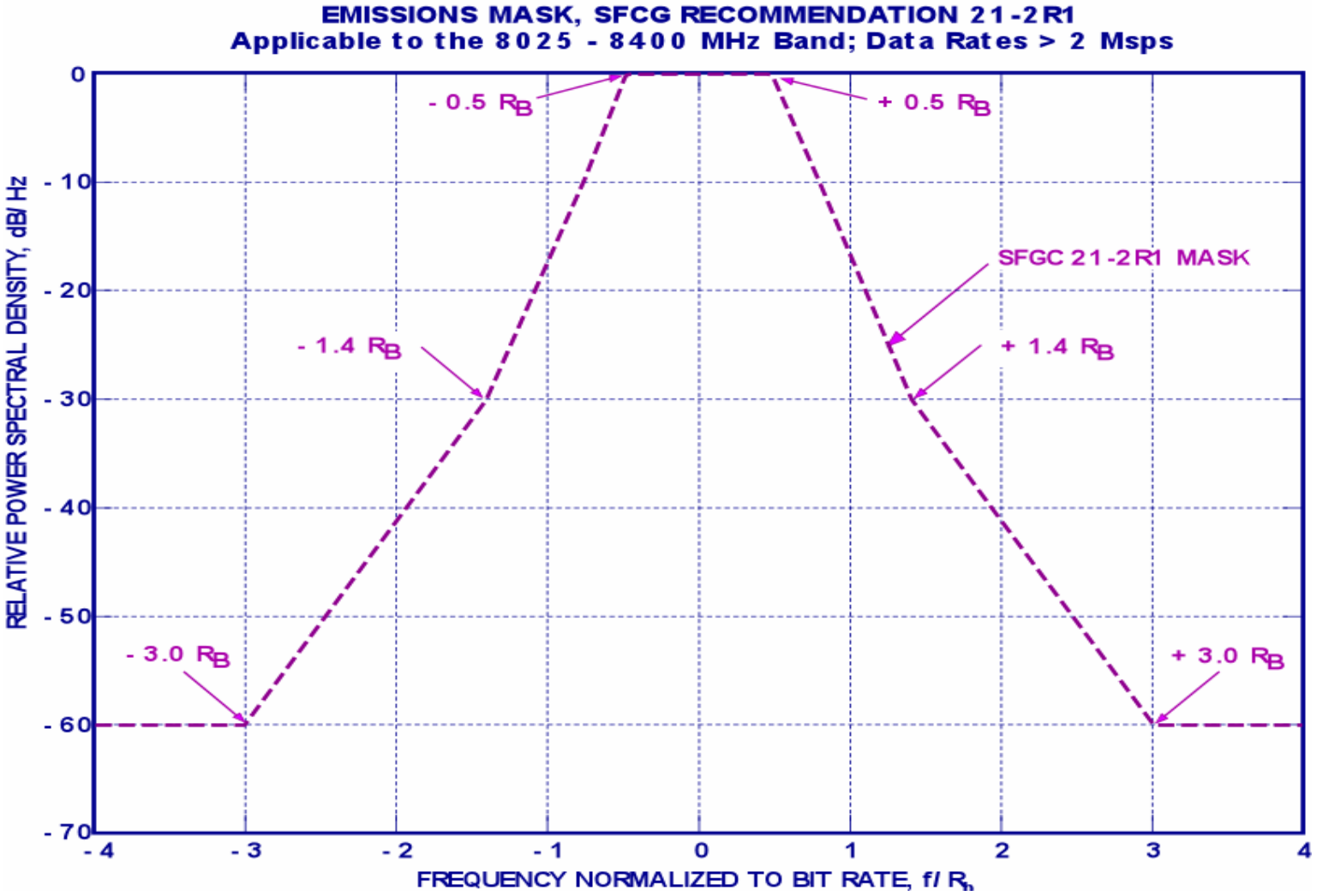
MODULATION TECHNIQUES
HISTORY OF CCSDS BANDWITH-EFFICIENT STUDIES

- 1990-91 - NEAR LOSS OF 2 GHz BAND TO PCS INDUSTRY CAUSES CONCERN
- 1992 - SPACE FREQUENCY COORDINATION GROUP (SFCG) ASKS CCSDS RF & MODULATION SUBPANEL TO RECOMMEND IMPROVED MODULATION METHODS
  - INTERNATIONAL EFFORT MOUNTED TO STUDY BANDWIDTH-EFFICIENT MODULATION
- 1993-94 - PHASES 1 & 2: ASSESSED COMMON MODULATION SCHEMES & FILTERING
- 1997 – PHASE 3: STUDIED SEVERAL MODULATION TYPES BOTH COMMON & NEW
  - PCM/PM/NRZ – PCM/PM/Bi-Ph – BPSK – QPSK – OQPSK
  - MSK – 8-PSK – GMSK – FQPSK-B – 4D 8PSK TCM (CNES 98)
  - FOUND BASEBAND FILTERING IMPROVED BANDWIDTH-EFFICIENCY BY MANY TIMES
  - QUANTIFIED END-TO-END LOSSES, TRELLIS DEMOD. REDUCES GMSK & TOQPSK LOSSES
- 1997 – SFCG ADOPTS REC. 17-2 SPECTRUM MASK (MODIFIED TO 17-2R1 IN 1998)
- 1999 – PHASE 4: EXPLORED SUCEPTIBILITY TO INTERFERENCE, FOUND:
  - INTERFERENCE SUSCEPTIBILITY DETERMINED BY RECEIVER'S MATCHED FILTER
- SFCG MASK RECOMMENDATION MODIFIED AGAIN IN 2001, NOW REC. 21-2R1
  - SUBSTANTIALLY SAME MASK AS IN REC. 17-2R1
- CCSDS ADOPTED MODULATION RECOMMENDATIONS IN JUNE 2001
  - 401 (2.4.17A) B-1 (CAT A), 401 (2.4.17B) B-1 (CAT B), AND 401 (2.4.18) B-1 (EES)
  - FOCUS WILL BE ON 401 (2.4.18) B-1 FOR EES MISSIONS; 4D 8-PSK TCM

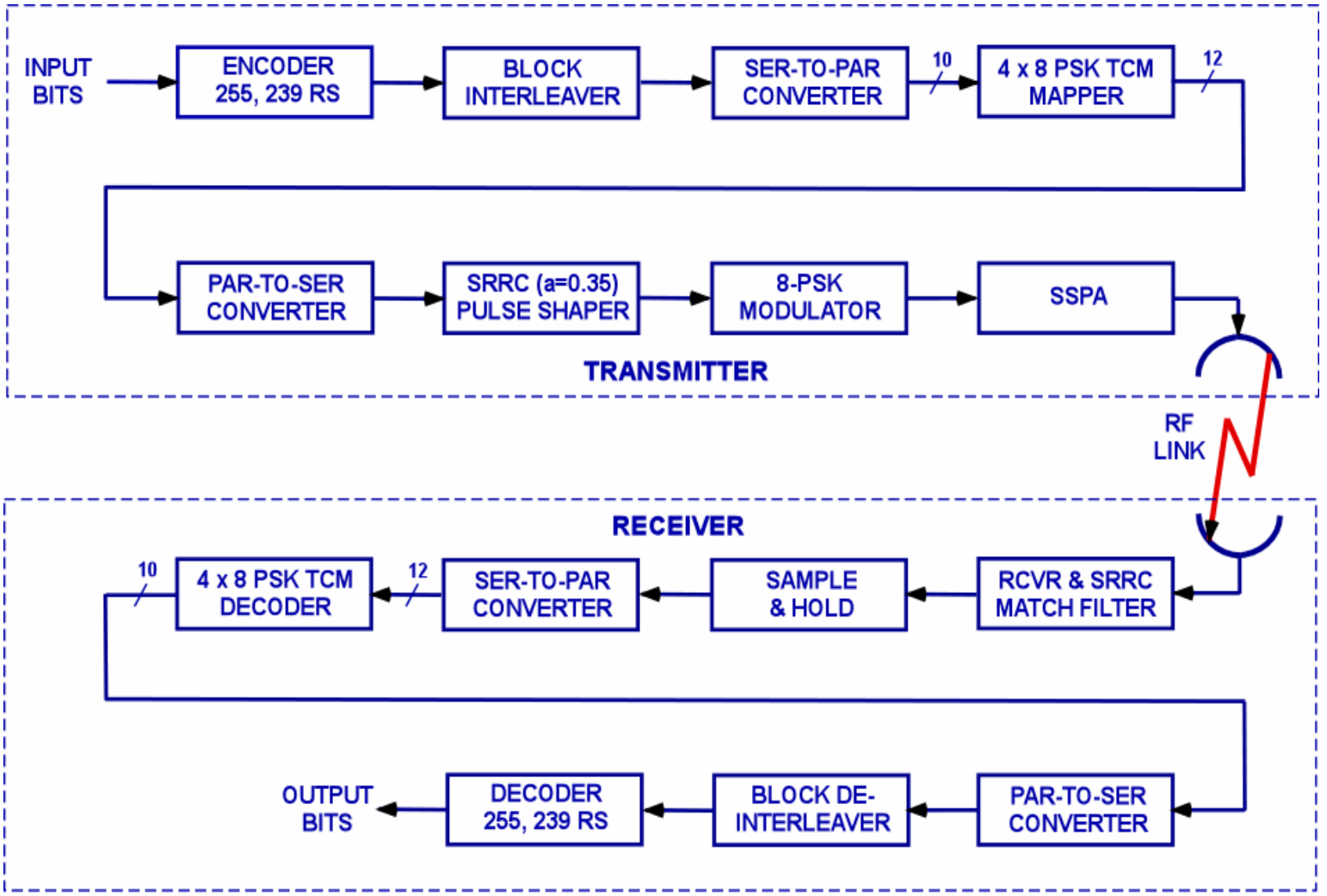
MODULATION TECHNIQUES

SFCG SPECTRAL EMISSION MASK (Rec.21-2R1)



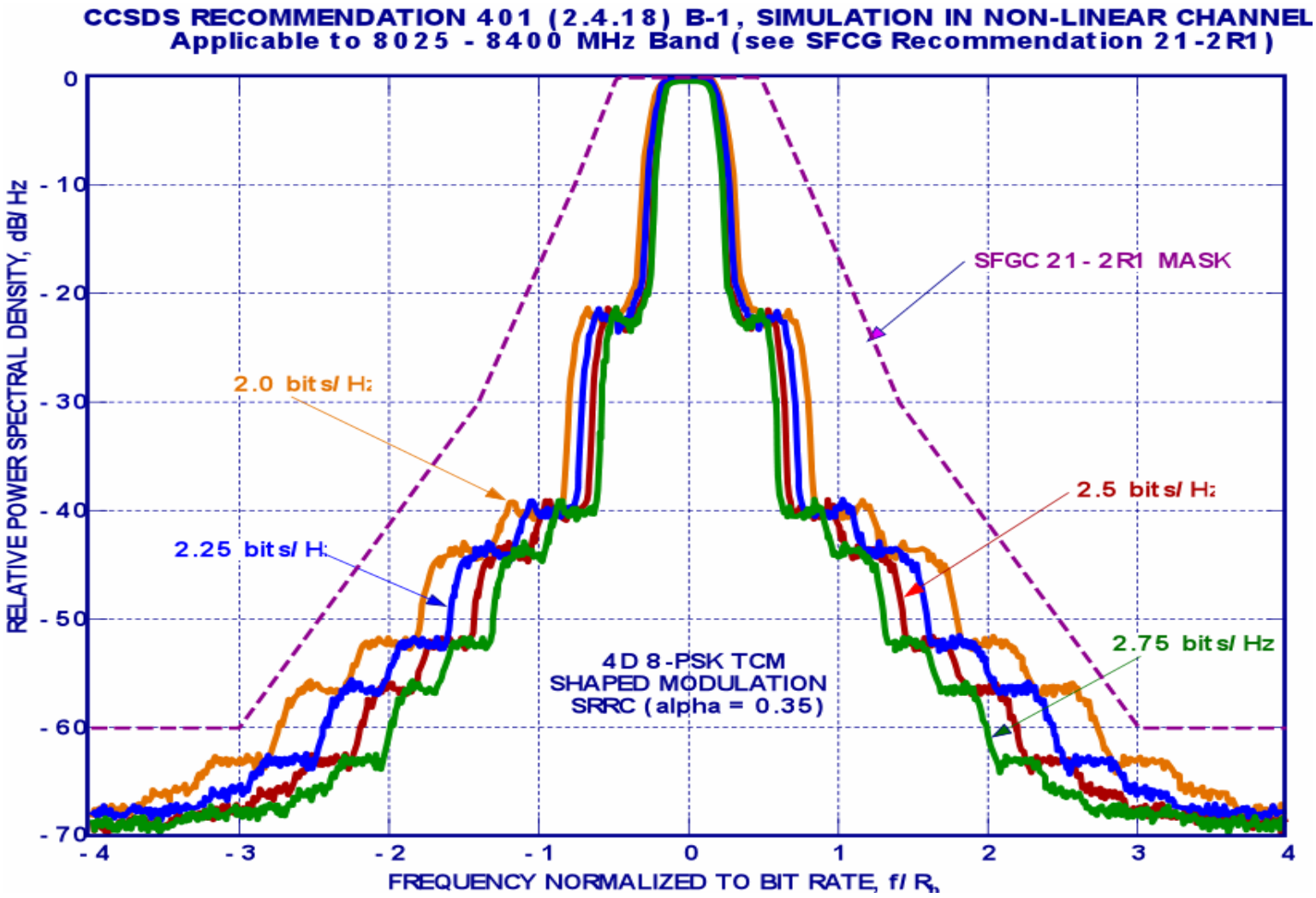
MODULATION TECHNIQUES

4D 8-PSK TCM SYSTEM IMPLEMENTATION, 2.5 Bits/Hz



MODULATION TECHNIQUES

4D 8-PSK SPECTRA (CCSDS Rec. 401 (2.4.18) B-1)



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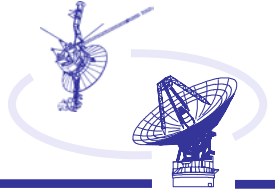
MODULATION TECHNIQUES
SYSTEM PERFORMANCE

- END-TO-END LOSSES COMPUTED RELATIVE TO IDEAL UNCODED BPSK
  - 4D 8-PSK TCM SELECTED BY CCSDS FOR LOW END-TO-END LOSSES AT 2.0 & 2.25 b/Hz
  - HOWEVER, BANDWIDTH EFFICIENCY IS NOT OUTSTANDING AT THESE EFFICIENCIES

BANDWIDTH EFFICIENCY (bits/Hz)	4D 8-PSK TCM PERFORMANCE			
	4D 8-PSK TCM (No Add'l Coding)[1]		4D 8-PSK TCM with RS 255, 239 Coding[2]	
	End-to-End Gain [3] (dB)	Reqd. E_B/N_0 (dB)	End-to-End Gain [3] (dB)	Reqd. E_B/N_0 (dB)
2.00	2.8	6.8	5.2 [3] (1.8) [4]	5.3
2.25	2.1	7.5	-	-
2.50	1.2	8.4	3.1 [3] (-.3) [4]	7.4
2.75	-0.2	9.8	-	-

NOTES:
1. Performance at BER = 1 x 10^{-5}; obtained by simulation employing model for fully saturated ESA power amplifier.
2. Performance at BER = 1 x 10^{-6}; fully saturated ESA power amplifier; RS interleave depth = 5.
3. Gain Computed relative to ideal uncoded BPSK.
4. Gain Computed relative to ideal BPSK with Convolutional (r=½, k=7) + RS (255, 223) coding.

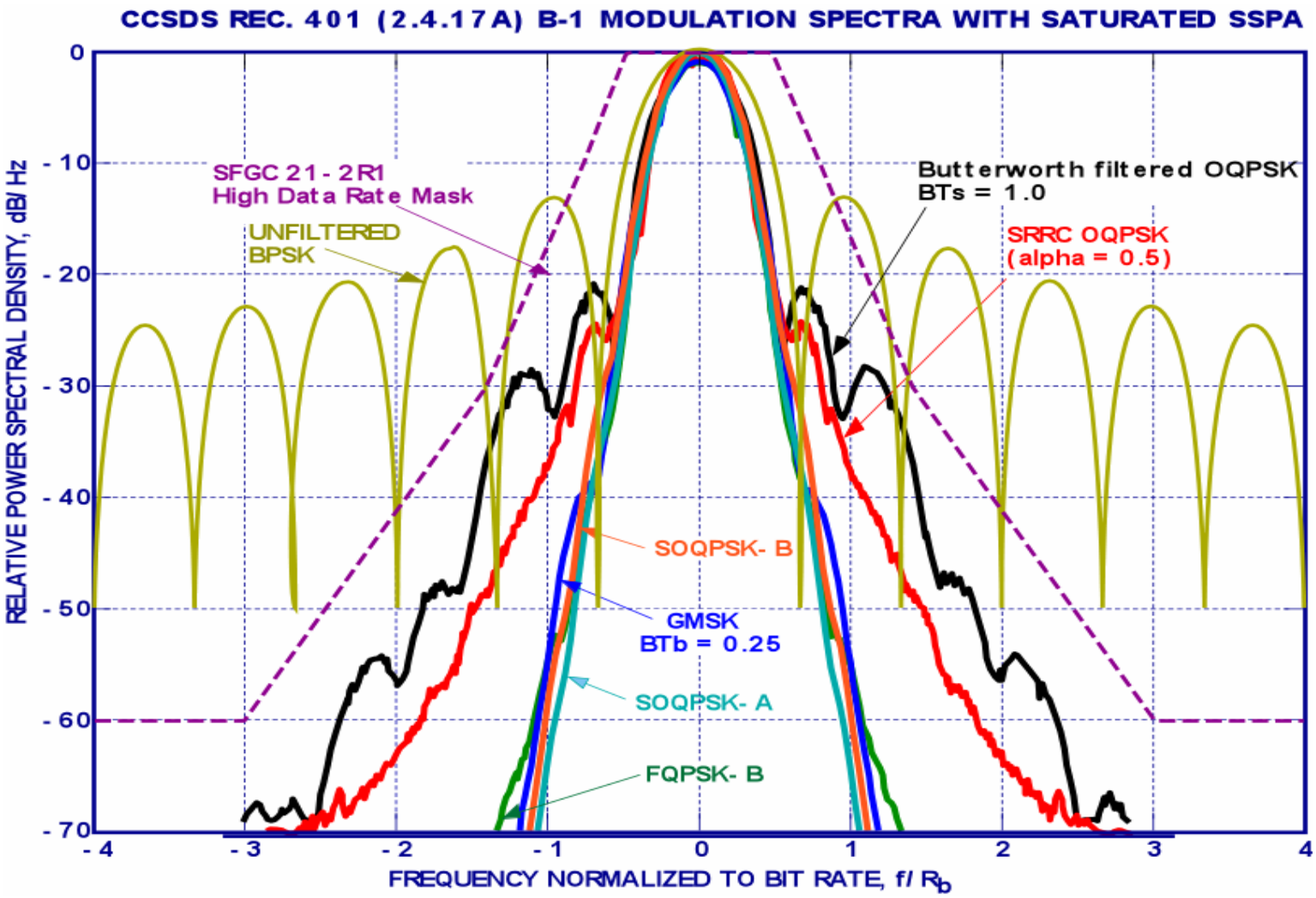
- INTERFERENCE SUSCEPTIBILITY DETERMINED BY RECEIVER'S FILTER
  - NO CNES MEASUREMENTS FOUND FOR THIS MODULATION TYPE



BACKUP

MODULATION TECHNIQUES

MODULATION SPECTRA, CATEGORY A SR MISSIONS



MODULATION TECHNIQUES
SYSTEM PERFORMANCE, CATEGORY A SR MISSIONS

- TRELLIS DEMODULATION CAN BE USED TO REDUCE END-TO-END LOSSES
- LOSSES BASED ON RECEIVER MATCHED FILTER

MODULATION TYPE (Name)	END-TO-END PERFORMANCE [1]			
	No Additional Coding [2]		With Convolutional + RS 255, 223 Coding [3]	
	End-to-End Loss [4] (dB)	Reqd. E_b/N_0 (dB)	End-to-End Gain [4] (dB)	Reqd. E_b/N_0 (dB)
GMSK (BT = 0.25)	- 0.4	10.0 dB	7.8 [4] (- 0.15) [5]	2.7 dB
GMSK (BT = 0.50)	- 0.1	9.7 dB	7.9 [4] (- 0.05) [5]	2.6 dB
FQPSK-B	- 0.8	10.4 dB	7.6 [4] (- 0.35) [5]	2.9 dB
SRRC OQPSK (α=0.5)	- 0.9	10.5 dB	7.7 [4] (- 0.25) [5]	2.8 dB

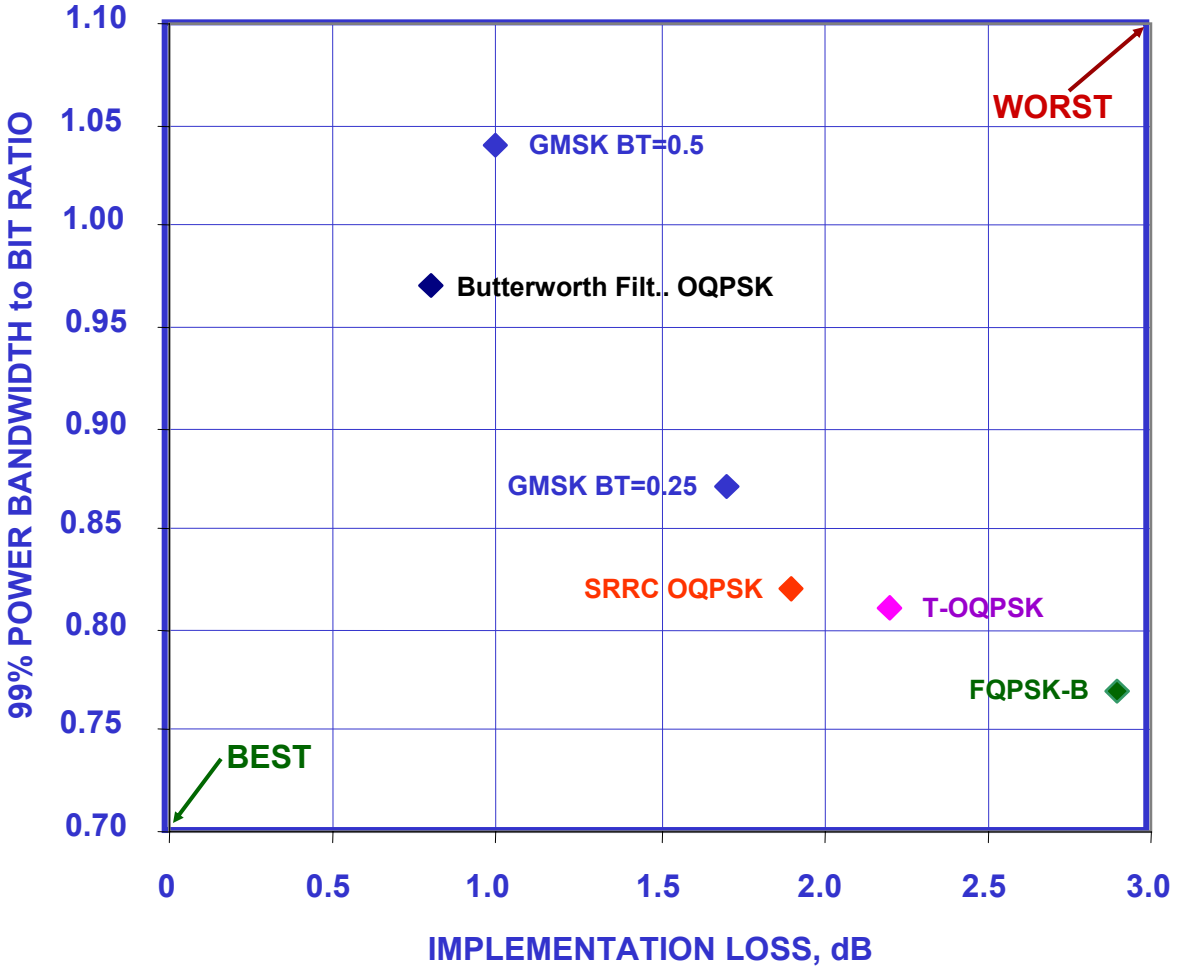
NOTES:
1. Performance obtained by simulation employing model for fully saturated ESA power amplifier.
2. Receiver type = trellis demodulation for GMSK and FQPSK, matched filter detection for SRRC OQPSK; BER = 1×10^{-5}
3. Receiver type = quasi-matched filter filter; 3-bit Viterbi metric quantization; BER = 1×10^{-6}
4. Losses computed relative to ideal uncoded BPSK.
5. Losses computed relative to ideal BPSK with Convolutional (r=½, k=7) + RS (255, 223) coding.

- INTERFERENCE SUSCEPTIBILITY DETERMINED BY RECEIVER'S FILTER
  - EVALUATED BOTH NARROWBAND (SINGLE TONE) & WIDEBAND (BPSK) INTERFERORS
  - FOR EQUAL VICTIM – INTERFEROR POWER LEVELS
    - NARROWBAND VICTIM LOSSES < 0.5 dB AT ± 0.5 R_B
    - WIDEBAND VICTIM LOSSES < 0.5 dB AT ± 1.2 R_B

MODULATION TECHNIQUES

MODULATION PERFORMANCE, CATEGORY A SR MISSIONS

MEASURED IMPLEMENTATION LOSS
(RELATIVE TO IDEAL BPSK)
JPL BLOCK V RCVR, 99% POWER BANDWIDTH, INTEGRATE & DUMP FILTER
UNCODED BER = 1 x 10^{-3}



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MODULATION TECHNIQUES
REFERENCES

- **WEB SITES CONTAINING USEFUL INFORMATION**
  - JPL INTERPLANETARY NETWORK, DSMS, FUTURE MISSION PLANNING OFFICE AT:
    - http://deepspace.jpl.nasa.gov/advmiss/index.html
  - CCSDS PUBLICATIONS AT:
    - http://www.ccsds.org/publications.html
  - SFCG AT:
    - http://www.sfcgonline.org/
- **DOCUMENTS**
  - *Proceedings of the CCSDS RF and Modulation Subpanel 1E Meeting of May 2001 Concerning Bandwidth-Efficient Modulation*. Yellow Book. Issue 2. June at:
    - http://www.ccsds.org/CCSDS/recent.jsp
  - CCSDS RECOMMENDATIONS AND REPORTS AT:
    - http://www.ccsds.org/CCSDS/recommandreports.jsp
  - SFCG HANDBOOK AT:
    - http://www.sfcgonline.org/handbook/index.shtml